Flotation – a combined unit for tertiary treatment and treatment of overflow effluent

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Abstract: Flotation equipment built for tertiary treatment can be utilized for treatment of storm water and other by-pass effluents of the biological process with minor additional investments. The ability of flotation to treat also high solid loads and bulking sludge makes it superior compared to other technologies. The full scale processes confirm that high rate flotation can successfully be used for these applications.

Introduction

The effluent requirements are going to be tightened with implementation of the water framework directive probably to a level of 0.15 mg P/l (Uijterlinde et al 2005). To reach these demands tertiary treatment and also management of overflows have to be taken care of. 2% of bypass flow cause about 0.1 mg/l increase in the effluent concentration. The permissions may require chemical treatment for the by-pass effluents.

Tertiary flotation can be utilized for treatment of storm water peaks in case the unit is designed to handle the solid quality thick surface sludge. Because of this feature the cost for improved water quality are low compared to other technologies applied for stormwater and/or tertiary treatment.

Today flotation is a rather unknown technology at municipal effluent treatment. Traditionally flotation has been utilized for treatment of process waters in pulp and paper industry and for oily and greasy wastewaters. Because of its compactness and efficiency flotation technique became common at potable water treatment plants. It has also been utilized successfully for simultaneous precipitation especially in Norway and this technology is becoming more common also for tertiary treatment of waste waters. The most significant benefits are efficient treatment results also in case of serious bulking problems and the option to use the system for by-pass water treatment. The sludge is concentrated, it can be dried without additional thickening and it does not increase the internal water cycles like other alternative techniques.

A typical surface load for flotation is nowadays on a level of 7 m/h but high rate flotation types are also available for 30 – 40 m/h surface load.

Flotation process

Microflotation (= dissolved air flotation) is a process used to separate solid particles from liquid with the aid of air bubbles. Very small air bubbles are created by dissolving air in water under pressure followed by release of pressure in a flotation basin. The bubbles attach to the particles and they rise to the surface. The sludge is scraped off from the surface. Chemicals can be used to precipitate soluble material and to increase separation of particles. At potable water treatment typically a flocculation time 15 – 30 min has been used before the flotation. With better understanding this has reduced to 5 minutes. The industrial flotation systems are often without the flocculation basin or the residence time is short (figure 1). The air bubbles can be produced also by dispersing air to water (dispersed air flotation) or by direct-current electricity (electroflotation). The bubble size and size distribution affect on the separation efficiency.

The key benefits for flotation process are high separation efficiency for bulking sludge, the capacity of tolerating high solid-load fluctuations, thick sludge, small space requirement and low residence time. The drawbacks are high energy consumption and need for chemicals. However, when used for tertiary treatment the chemical consumption can be decreased correspondingly in other parts of the process. The total costs for flotation and competing technologies consist mainly of the capital costs.

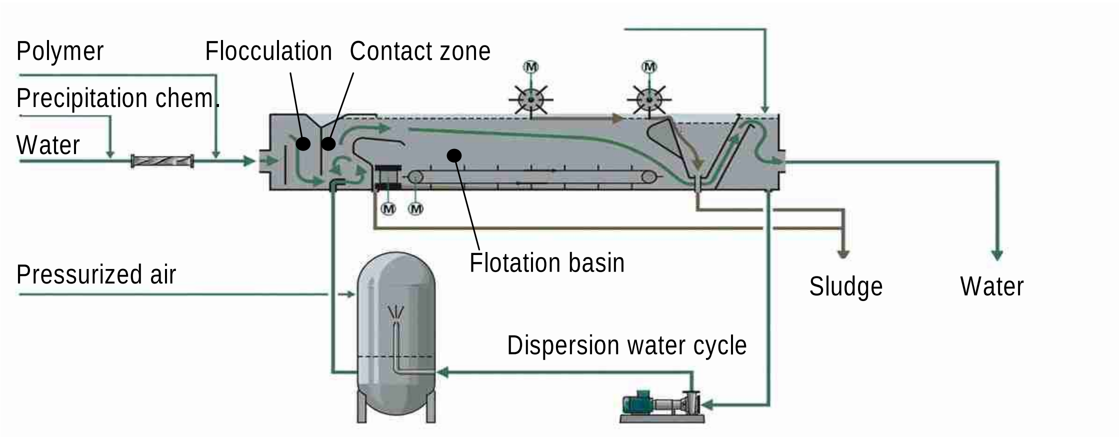


Figure 1. A principal diagram of a flotation process (Eimco, Optidaf)

Technical solutions and general applications

Flotation has been used more than one hundred year. It is widely used in industrial processes, e.g. in separation of oils and fats and in treating process water cycles in paper industry. In some cases the feed water contains 1000 – 2000 mg/l and even 6000 – 10000 mg/l clay and fiber which are removed in flotation to a level of 20 – 100 mg/l.

Dissolved air flotation for potable water treatment became common in Scandinavia in the 1960's. The benefits of the process were its compact nature and ability to treat cold, soft coloured waters and the fact that no polymer addition was required. During 1970's the process was launched to UK particularly for waters that suffered algal blooms. In UK it came popular in the early 1990´s and has spread after that to North American and Asian markets.

The biggest plants treat over million m^3/d water (Tai Po/Hong Kong 1 200 000 m^3/d; under construction New York 1 100 000 m^3/d). The smallest commercial units are for 1 m^3/h.

The knowledge of the flocculation and flotation processes as well as the equipments has developed remarkably during the past years. During 1980´s a typical surface load was 2 - 4 $(m^3/h)/m^2$, when it is now on a level of 7 m/h. There are new high rate flotation types (Crossley and Valade 2006) available which can be applied for 30 – 40 m/h surface load with efficient solid separation in potable water and effluent treatment (Anamoto et al 2001).

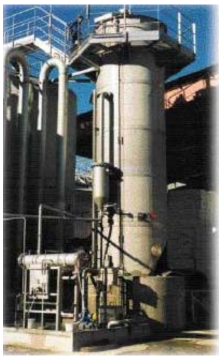
The flotation basins can be round, square; shallow or deep (figure 2). The shallowest ones have 60 cm water depth for capacities of several hundreds m^3/h (fig 2a). However, these require under them room for external devices. The square units utilize the room more efficiently and especially when they are constructed so that all external devices can be installed on the same floor and no walkways are needed for maintenance (fig. 2b). The vertical plate flotators are able to treat more than 100 $(m^3/h)/m^2$ water calculated per floor area (figure 2c).

The high rate flotation units can be manufactured at workshops for rather high capacities. E.g. a transportable 35 m^2 unit is able treat 10 000 m^3/d water.

Most of the flotations in effluent treatment are based on microflotation. There is also development on dispersed air flotation, which uses less energy and applications, in which the flotation unit is added to the end of the existing clarification units (Kiuru and Tran Minh 2007).

a

b



c

Figure 2. Flotation units

Some of the equipments are so high that they need a separate platform for control and maintenance (figure 3b). This influences on the total construction costs which should be taken into account when comparing the alternatives.

Sometimes the flotation can be installed into existing clarification basins (e.g. Vaasa wastewater treatment plant), which may reduce the costs. The biggest single units have been built based on this principle (e.g. Ipoh/Malaysia a´ 225 m^2. Capacity 275 000 m^3/d treating river water from inlet turbidity of 80 – 400 NTU to 2 NTU residual turbidity).

In effluent treatment high amounts of thick sludge is produced. The surface sludge systems need to be designed for that (figure 4). When raw, screened effluent is treated, the unit should be equipped with bottom sludge removal and especially the dispersion water system has to be designed to tolerate the solids in the pre-screened effluent. The flotation units used for potable water treatment are often designed for small sludge amounts and only for fine particles. Without modifications these may not fulfil the practical requirements for effluent treatment. Flotation units which are used in paper industry are often suitable also for effluent treatment.

3a

3b

Figure 3. Dispersion nozzle systems in two cases – on the left a unit with 12 nozzles, at right 320 nozzles). The hydraulic capacity of each unit is 750 m^3/h

4b

4a

Figure 4. Surface sludge can be removed using chain scrapers (4a) or (4b) sludge rollers (flippers)

In potable water treatment and in pulp and paper industry there are fully automated plants which need only minor supervision and maintenance.

In effluent treatment the units should be robust and designed to handle hairs and sand as well as high amounts of thick and sticky surface sludge. If the technical construction of the unit is not in balance with the application it will require excess maintenance and manpower.

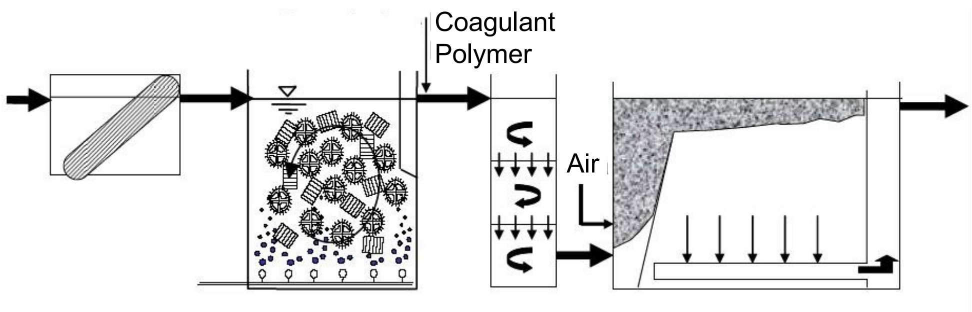
Flotation for direct precipitation and by-pass effluent treatment

In Norway there are several flotation units in direct precipitation. Often only high SS and P removal has been required and the compact flotation units have been the most economic alternatives in several cases. Odegaard (2001) has evaluated the treatment efficiencies of these direct-precipitation flotation processes in size classes of >2000 population equivalent (=pe) units (23 pc) and <2000 pe (25 pc). The average surface loads were 2 – 5 m/h and the units reached 0.06 – 0.4 mg/l residual phosphors concentration (92 – 98 % P removal) and about 70 – 90%:n COD-removal. The average solid reduction in both size classes was more than 90% and the BOD reduction was on the same level.

In municipal effluent treatment using efficient process control and chemical dosage, 95 % phosphor and solid reductions as well as 70 - 90 % BOD- and COD-removal can be achieved. Nitrogen removal is typically 20 – 30%. The chemical dosage can easily be controlled due to short residence time. Influent and effluent turbidity measurements help in saving of chemicals.

In direct precipitation the BOD-reduction in flotation is clearly better (>90%) than can be achieved by using precipitation and sedimentation (50 – 80% BOD removal).

Odegaard et al. (2004) have described a method for improving the BOD removal in compact systems (figure 5). This includes a fine screening and biofilm process with 15 – 30 min residence time before the flotation. The solutions in which flotation is followed directly after integrated biofilm activated sludge process are familiar in pulp and paper industry (Huhtamäki 2000).



Fine screen	Biofilm process	Flocculation	MIcroflotation
≤1 mm	10 – 30 min 17–24 g $BOD_{7\ filtr.}$ /m^2,d	Polymer 1 mg/l + Fe^{3+} 7 mg/l (e.g. ferri 70 mg/l). Dosage based on SS Flocculation 5 – 10 min	(Surface load 5 – 15 m/h)

Figure 5. High rate biofilm process and flotation in effluent treatment

The quality of by-pass effluents is similar to raw influent except that they are more diluted than typical raw water. If a flotation unit is built for tertiary treatment, the same unit might be used for by-pass effluent treatment assuming that it can handle the solid load and quality.

In Finland at Vaasa and Raisio the flotation units are used for treatment of by-pass effluents when needed. At Raisio 90% reduction for BOD, SS and P were reached for by-pass effluent at 10 m/h surface load (April and October 2006). The effluent quality for these parameters after flotation was close to the biologically treated effluent quality (Table 1 and figure 6). In Vaasa similar results are reached.

Table 1. Treatment efficiencies for flotation in by-pass effluent treatment

	Vaasa; typical results			Raisio April 2006, (median)		
	From flotation	Influent	Reduction	From flotation	Influent*	Reduction
Suspended solids	12 - 18	200 –260	>90%	333	33	90 %
Phosphorus	0.4 – 0.5	6 - 8	>90%	7,6	0.79	90 %
BOD7	8 – 12	120 - 150	>90%	239	16	93 %
Nitrogen					35	n.25%

* Snow melting period; temperature 6 ^{o}C

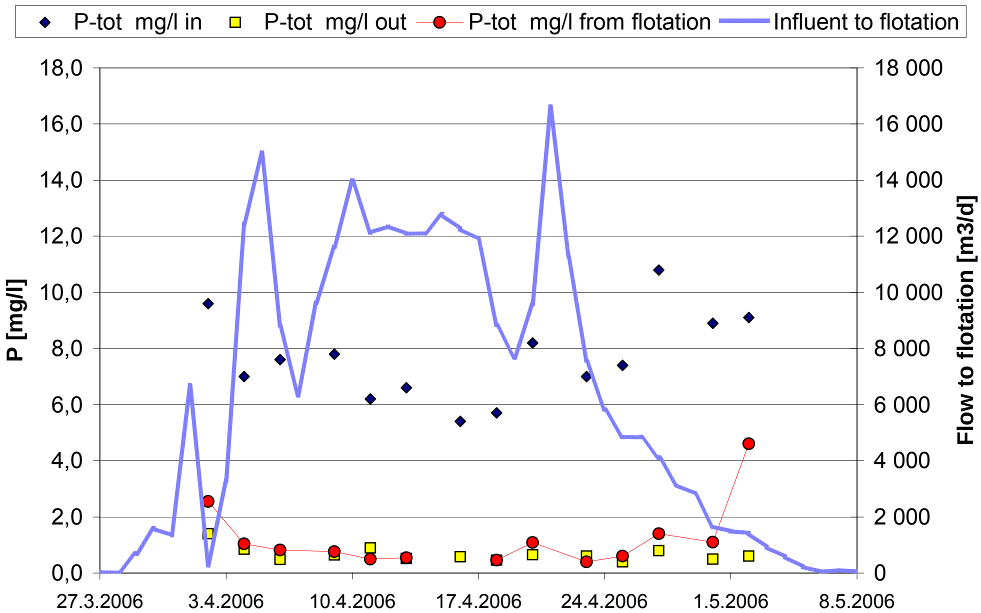


Figure 6. Treated by-pass effluent flow and concentrations in Raisio April 2006

Flotation in tertiary treatment

In Finland most of the existing flotation units for municipal effluent treatment are built for tertiary treatment during the 1970's and 1980´s. Units are e.g. at Vaasa (average actual flow 17000 m^3/d; 2002 - 2005 flow level), Raisio (11000 m^3/d), Pietarsaari (8500 m^3/d), Eura (7500 m^3/d), Pieksämäki (4500 m^3/d), Tammisaari (2800 m^3/d), Ähtäri (1800 m^3/d) and Laihia (1100 m^3/d).

As an example the flotation in Tammisaari is built in the middle of 1980´s. It is used full time for tertiary treatment separating about 90% of the suspended solids and phosphor from secondary treated effluent. The total P and SS reduction at the treatment plant is as yearly average about 99%. The chemical consumption at Tammisaari wwtp is remarkably lower compared to the Finnish municipal effluent treatment plants as an average (Kangas 2005). In this case 70 mg/l ferrosulphate is used for simultaneous precipitation and 60 mg/l aluminum sulphate for the flotation process. The surface load in secondary

clarification is on the average 0.2 m/h and max. 0.6 m/h and respectively in flotation on the average 1 m/h and max. 3 m/h. There are no by-pass effluents at the plant.

In Eura there is one of the newest municipal flotation units in Finland. There all the influent is first treated biologically and then post-treated with flotation. In Eura the old secondary clarification is overloaded. The surface load is > 1 m/h, which causes temporal high solid concentrations in the secondary effluent. The alternative in the rebuilding was to increase the capacity of secondary clarifying with a new unit and in addition to build sand filtration for tertiary treatment in order to reach the requirement for 0.3 mg P/l. Instead of this a flotation unit was built. Based on practical experiences and treatment results, the choice has been right. The removal efficiency for phosphorus and suspended solids is high independently on the incoming concentration. The analyses from year 2005 are shown in figure 7. The average concentrations were: SS 94 mg/l => 5 mg/l and P-tot 0.54 mg/l => 0.074 mg/l. The removed BOD and nitrogen correlate with the amount of removed suspended solids (0.3 mg BOD/mg SS and 0.03 mg N/mg SS). The average surface load for flotation has been 3 m/h.

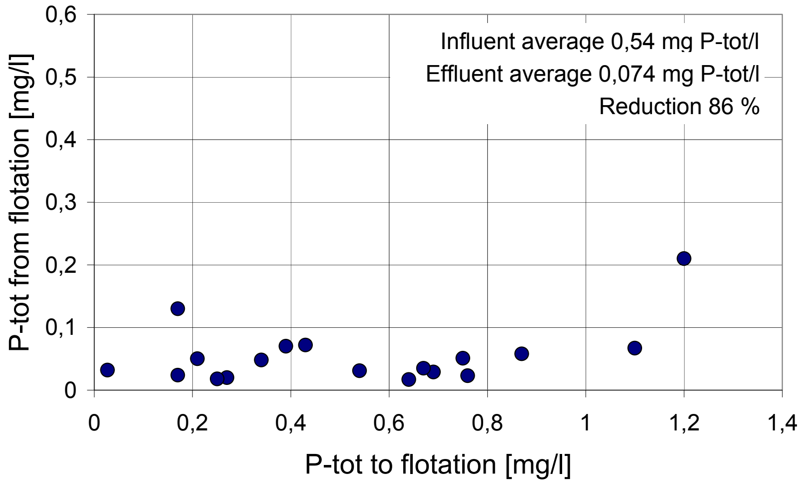


Figure 7. JVP-Eura Oy. Phosphorus removal in flotation post treatment year 2005.

The results from Raisio are not as good as they are e.g. from Tammisaari or Eura. The flotation is used for post treatment since end of April 2007. The pumps are placed directly into the secondary clarification, which causes turbulence in it and sometimes high solid load to the flotation. The chemicals are not optimized, but still < 10 mg/l and < 0,3 mg P is reached (Average concentrations in May 2007 SS 5,3 mg/l, BOD 3,4 mg/l, P-sol 0,14 mg/l, P-tot 0,27 mg/l and COD 39 mg/l).

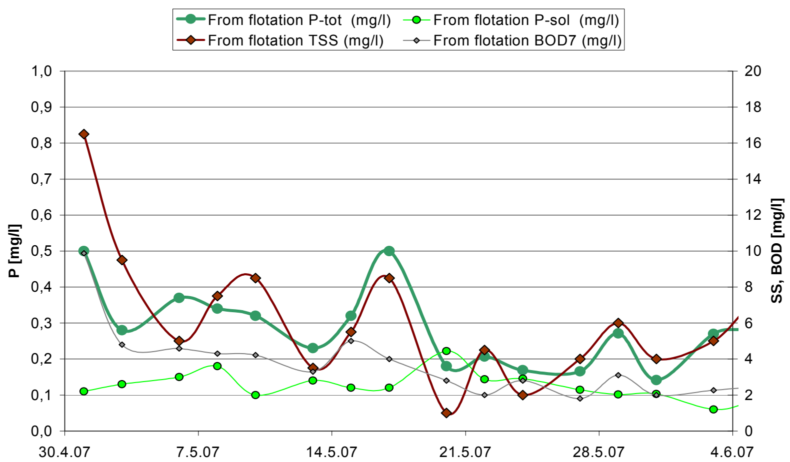


Figure 8. Raisio wwtp. Phosphorus removal in flotation post treatment year 2007

Economy and alternatives

Flotation technology has developed remarkably during last years. Although the energy requirement is reduced, it is still high compared to sand filtration. The capital costs play the major role in using of these technologies and they have to be evaluated case by case. A post-treatment flotation can also be used for treating by-pass effluent, which may be in some cases important. The key technologies used for tertiary treatment are compared in tables 2 and 3.

Table 2. Alternative technologies for tertiary treatment

	Clarification	Flotation	Sand filtration	Membrane filtration
For post-treatment				
P-removal	OK	OK	OK	OK
Normal post-treatment	OK	OK	OK	OK
Separation of bulking filamentous sludge	**NO** (does not clarif.)	OK	**NO** (blocking)	(MBR-systems OK)
For by-pass effluent				
Operability	OK	OK	Not used (blocking risk)	Not used (expensive)
Max surface load	2 – 4	7 - 40		
Notes				
Impact on capacity	Sludge is difficult to be thickened. May need more capacity there	Sludge 2-5 % TS. Can be directly dewatered	Wash water recycle reduces the wwtp hydraulic capacity by 10-20 %	Concentrate reduces the wwtp hydraulic capacity by 10-20 %
Other notes	Is not efficient for bulking sludge	Tolerates high solid fluctuations 10-2000 mg/l SS	Blocking risk for bulking sludge	Capacity decreases for higher solid loads
Power requirement	0.02 kWh/m^3	0.08 kWh/m^3	0.04 kWh/m^3	1 – 3 kWh/m^3

Table 3. Investment and operation costs

	Clarification	Flotation	Sand filtration	Membrane filtration
Magnitude for Max flow. 500 m^3/h; aver flow 250 m^3/h	0.6 MEUR	0.6 MEUR	0.6 MEUR	3 MEUR
Capital costs	4 c/m^3	4 c/m^3	4 c/m^3	20 c/m^3
Electricity	0.15 c/m^3	0.6 c/m^3	0.3 c/m^3	7 - 20 c/m^3
Other utilities		0.01 c/m^3	0.01 c/m^3	>0.5 c/m^3
Other cost factors	-	Pressure air	Sand	Membranes, chemicals
Sludge thickening	Is needed	Not needed	Is needed	Is needed
Pumping requirements	Sludge recycle	-	Wash water10%	Concentr 10-20%
To be noticed in investment calculations	Space requirement Chemical dosage Sludge treatment	Space requirement Chemical dosage Sludge treatment	Building Chemical dosage Water recycle. Wash water reservoir.	Building Chemical dosage water recycle

The investment costs may depend a lot on local suppliers, conditions and requirements. The comparison is targeted only for giving ideas of the cost magnitude.

Supplying and operation of a flotation process

Investing of the process

At waste water treatment plants where post clarification is wide enough, it is possible to reach 0.1 mg P/l residual phosphorus level by optimizing the used chemicals and by minor improvements (Jokinen 2005). This alternative should be studied first. If there is a need to invest in a separate post treatment unit flotation is a considerable alternative for sand- and other filtrations.

Flotation used in effluent treatment should be robust and designed for this purpose. In potable water treatment plants and in pulp and paper industry there are fully automated plants which need only minor supervision and maintenance. In these applications the reliability and operability are the major selection criteria.

Regarding to the evaluation of reference plants, e.g. the requirements for potable water treatment and pulp and paper industry are quite different concerning the influent solid amount and quality. In pulp and paper industry the waters contain hundreds or thousand of mg/l fiber and clay containing solids. The water quality in municipal effluent treatment plant resembles more the paper industry waters and typically the units targeted for paper industry can be applied also for effluent treatment.

Most of the units designed for potable water treatment are not capable to treat the solid quality and the amount which has to be separated at municipal effluent treatment without modifications and/or excess maintenance and manpower.

In municipal effluent treatment the flow variation between day and night time and dry and wet seasons are much higher than in other applications. This has to be taken into account in flotation level control and sludge removal system. The separated surface sludge can be thick (often 5 – 6% TS) and sticky e.g. in bulking sludge situations, which have to be taken into account in design.

If the unit is designed both for tertiary treatment and for by-pass effluent treatment, the future 0.1 – 0.15 mg/l P level may be reached without additional investment.

Automation and operation of the unit

The chemical dosage and control of the purification efficiency can be arranged cost-effectively by installing turbidity analyzers for flotation influent and effluent. Even in case they don't directly control the chemical system and dispersion water system, they can give valuable information for optimizing the treatment efficiency and operational costs.

Typically the result can be improved by using coagulants and/ or flocculants. The suitable chemicals / chemical combinations depend on the influent quality and biological process and they should be tested case by case. The amount of flocculant (polymer) depends on the influent solid concentration. In exceptional situations, when the influent solid concentration is high (e.g. heavy bulking sludge > 1000 mg/l) both the chemical dosage and the dispersion water cycle have to be increased (more air bubbles are needed to lift the particles).

The dispersion water system is typically designed for 6 – 10 bar pressure. That is often also the operation pressure, although a 2-3 bar pressure in the dispersion water system would be enough for efficient solid separation. In large treatment plants the pressure can be controlled based on turbidity measurement – if the measurement exists and if the unit is designed for pressure control. In smaller plants however, simple robust systems may be more economic than very sophisticated ones.

In case of poor treatment results the reason can typically be found in the following list

- Disturbances in chemical dosage
- Exceptional high incoming solid load, which would need more chemicals and/or higher dispersion water cycle or pressure.
- Mechanical problems in pumps, scrapers etc.
- Flocs are not generated – chemicals should be dosed or the chemical type should be changed

Conclusions and discussion

Flotation is proven to be an economic and efficient alternative in effluent treatment. It is anticipated that the technology is going to be more common also for effluent treatment. The higher energy costs for flotation are compensated typically with lower capital costs and better purification efficiency.

Tertiary treatment is needed above all during serious bulking sludge situations. This is often neglected in purchasing stage. In such situations the sand filtration may be blocked and it is often by-passed. The treatment results of flotation are excellent under such conditions.

The practical results have showed that for tertiary effluent treatment in normal conditions the results for flotation and sand filtration are on the same level.

The tighter requirements in future may require that all effluents passing the biological treatment should be purified chemically. That can be done by using clarification or flotation. These alternatives are both efficient for solid and phosphor removal, but the BOD removal efficiency in flotation is higher. The benefit of a flotation unit is that the same unit which is used for by-pass effluent treatment can be used for tertiary treatment when there are no by-pass effluents.

In effluent treatment high amounts of thick, sticky sludge may be produced. The sludge removal system in flotation has to be designed for this purpose.

In effluent treatment the units should be robust and designed to handle hairs and other particles passing through the pre-screening, especially when also by-pass effluents are treated. The treatment of by-pass effluents should be taken into account for the future requirements.

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